# Simulation Studies for ICAL Detector at India-based Neutrino Observatory.

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## Introduction

With the proposed project of India-based Neutrino Observatory (INO)[1], India has joined the worldwide efforts made to understand the elusive particle, neutrino. INO will be an underground facility which will house different neutrino experiments. Primary experiment will be the Magnetized Iron CALorimiter (ICAL). ICAL detector in its first phase will study atmospheric neutrinos. With an additional ability to differentiate between neutrinos ($\nu$) and anti-neutrinos ($\bar{\nu}$) it will throw light on some of the unexplored areas of neutrino physics as it stands today. Apart from making more precise measurements of known atmospheric neutrino parameters like $|\Delta_{31}|$ and $\theta_{23}$, ICAL detector will also study the matter effect induced oscillation effects and will try to establish neutrino mass hierarchy.

Simulation studies were carried out to study the detector response which in turn determines the sensitivity of the detector for different oscillation parameters. It further helps in deciding detector parameters in order to improve the sensitivity to the oscillation parameters. Here we will discuss the simulation and reconstruction package developed for this purpose and the preliminary results obtained.

## Simulation studies

ICAL at INO will be a 50 kton detector of dimension 48m x 16m x 14m, with alternate layers of iron and the gas filled resistive plate chamber(RPC)[1]. Secondary particles which are produced in the interaction of atmospheric muon neutrino and detector material will be detected through the signal in RPC. Different neutrino interactions give different signals. In charged current interaction neutrino energy is shared between muon and hadrons, while in neutral current events we only see hadron signal. Muon being minimum ionising particle undergo multiple scattering in iron leaving long curved track where its radius of curvature is proportional to its momentum. Also, length of the track is proportional to muon energy in case of fully confined track. On the other hand, hadrons undergo strong interactions giving shower like feature. Thus, ICAL performs both as a tracking detector as well as a calorimeter.

Simulation and reconstruction package developed for ICAL consists of 3 parts, the *particle simulation*, *digitization* and *reconstruction*. Geant4 toolkit is used for detector simulation. Measurement uncertainties in the observed parameters and noise are added in the next step of digitization, which incorporates the position resolution, timing resolution, detector inefficiency etc. This data is then fitted using reconstruction algorithm to reconstruct 3-momentum of muon. Reconstruction algorithm first separates muon track from hadronic shower and the noise signals using pattern recognition algorithm. Track parameters are then obtained using Kalman filter technique [2]. Alternatively, for muon that was completely confined in detector volume, its initial energy can also be calibrated from the length of the path it traverses in the detector. The hadron hits close to the muon vertex are then separated, which are then calibrated to give hadron energy. Knowing muon and hadron energy, as the case may be, we reconstruct back the neutrino energy.

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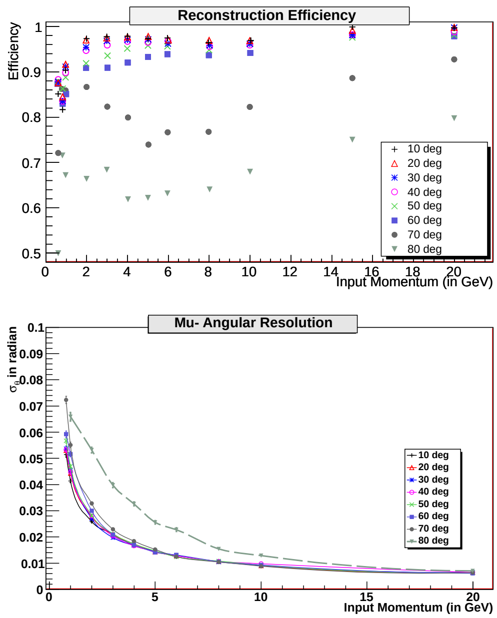


FIG. 1: (TOP) Reconstruction Efficiency; (BOTTOM) Angular Resolution.

## Preliminary results

For energy range of atmospheric neutrinos major fraction of the neutrino energy is carried away by the muon. Also because muon gives cleaner signal in ICAL detector, reconstructing its energy and angle with finer resolution becomes crucial for improving L/E resolution for measurement of oscillation parameters. Reconstruction results obtained by Monte Carlo muons in ICAL detector are shown in the figures above.

## Summary

Reconstruction efficiency is seen to worsen for horizontal-going muons (with larger $\theta$). For fully confined track, momentum resolution from path length will be used, as it has better resolution than that obtained from curvature method. Angular resolution, while good for higher energies, is poorer for lower energies. Work for improving the performance of the code is being carried out. Also inhomogenous magnetic field (from magnet simulation) is being incorporated to check the performance in

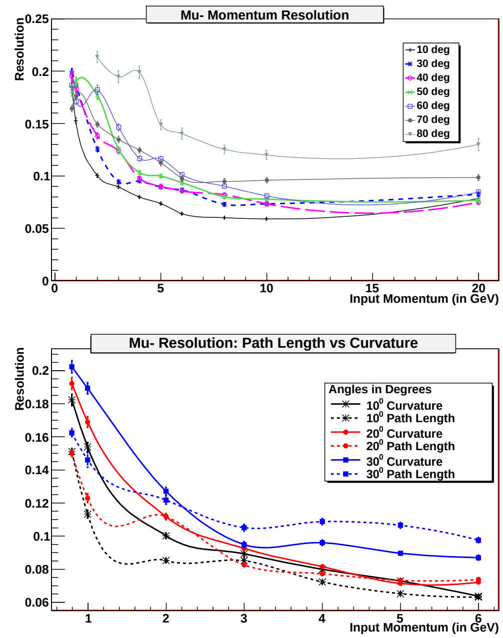


FIG. 2: (TOP) Momentum Resolution from curvature; (BOTTOM) Energy Resolution from curvature (solid line) vs Path Length (dashed line).

presence of toroidal magnetic field.

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## References

[1] INO-A Status Report (2006)
[2] A New Track Fitting Algorithm-John Marshall